Fog, Mist, Dew, and Other Sources of Water

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The main sources of water for crops in most agricultural areas are rain or irrigation. In many parts of the world, however, neither rain nor ground water seems to be enough to account for the development of the naturally occurring vegetation. In those places we have to look for other sources of water—fog, mist, and dew—and their possible contribution to plant growth.

On many days and in many localities, plants are covered with dew in the early morning. Because dew disappears soon after sunrise, people often overlooked it as a possible source of water, which they consider to be most necessary in midday. The question, however, is not whether water droplets stay on the leaves for a long time but whether the water can contribute in any way to the growth of plants. In other words, does enough of the dew water reach the soil or is a sufficient amount absorbed by the plant itself to improve the whole water supply?

The question has been investigated by S. Duvdevani, who compared two field plots of plants that were treated identically except for the possibility of dew formation at night. By placing a canopy over one plot between sunset and sunrise, he prevented formation of dew on the plot without interfering with the temperature or the movement of air over the plants. He conducted the experiments in the coastal plain of Israel, where dew occurs frequently and sometimes is rather heavy. The tests showed that most plants, such as squash and corn, grew about twice as much when they received dew during the night. Therefore it would seem that in a semiarid area, dew has considerable importance in the growth of plants. Three possible reasons come to mind.

In the first place, the dew water could run off the leaves and collect in the soil on which it drips. The amount of dew, however, is too small to wet more than a few millimeters of the soil.

In the second place, it is possible that the dew water is absorbed by the leaf surface, on which it condenses, and thus is used directly by the plant. That was found to be the case; young leaves especially can absorb the dew as rapidly as it forms. One can often observe that after a night of heavy dew the young leaves of shrubs and herbs are quite dry and the older ones are covered with dew. This absorbed water can be moved to other parts of the plant and can even be excreted by the roots into the soil. Such water would be available again the next day. It was actually found that the soil around root systems of plants is more moist when they are subjected to dew than around roots of plants that do not receive dew, despite the fact that the dew-covered plants are larger and must take more water from the soil.

In the third place, water saturation of a plant is essential for its growth. As growth in most plants occurs during night, a water supply would be most effective at night. These observations therefore make it very likely that dew can contribute to the better development of plants, at least in semiarid regions.

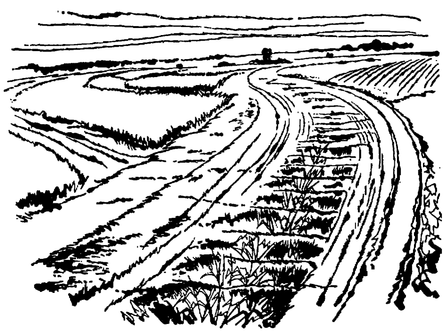
Experiments with the yellow pine by E. C. Stone and H. A. Fowells have shown that when yellow pines are grown in very dry soil, which is unable to supply water to plants like sunflower, they will survive for a limited number of weeks (on the average, 3); however, when such plants are sprayed every night with a fine mist simulating dew, they can survive for 7 weeks without any further water supply through their roots. That is another indication of the possible importance of dew in the life of plants.

Field observations also tend to indicate that there must be another source of water for plants in semiarid regions where rainfall is insufficient for normal growth of plants. As an example, the growth of a number of annual plants during the dry season in southern California can be mentioned. Some plants, among them the wild buckwheat (*Eriogonum fasciculatum*), some gilias, and *Stephanomeria*, manage to continue development many months after they have received the last rain.

If they had an extensive root system, they might be able to extract enough water from the drying soil, but these plants and others have only restricted root systems and few active rootlets. They certainly must have exhausted in a short time the small amount of soil with which they are in contact. When such plants still manage to keep green and even grow, it means that there must be another source of water than what is stored in the soil around their small root system. Because their water requirement cannot be satisfied from below, it must come as atmospheric condensation.

Is dew a frequent enough phenomenon and is it of sufficient intensity to account for its apparent role in plant growth as demonstrated in the examples I mentioned?

To get an answer to that question, many investigators have devised methods to measure dew under natural conditions. They have used various gages. The one most extensively used and accepted is that of Dr. Duvdevani. It is a wooden block with a standardized painted surface, which is exposed to dew at night and on which the occurrence and quantity of dew can be read in the morning according to the pattern of dew droplets deposited. The heavier the dew, the more the droplets have coalesced. By comparing the dew patterns with photographs, one can standardize the observations. With the gages Dr. Duvdevani studied the distribution of dew in Israel and found four interesting relationships.



FIRST, THE AMOUNT of dew is higher in the dry summers than in the wet winters.

Second, even in the dry and hot Jordan Valley dew is a common phenomenon and occurs on nearly half the nights. In the Southern Desert (Negev) it is even more frequent.

Third, considerable differences exist in dew deposition according to the topography of the land.

Fourth, deposition of dew in summer increases with distance from the ground, but in winter the opposite dew gradient is found—proof that the water deposited as dew did not originate from the ground but was of atmospheric origin. The total amount of dew precipitation in Israel amounted to approximately 1 inch a year.

Other investigators found a similar figure in other parts of the world and therefore concluded generally that dew could not account for more than 1.5 inches of precipitation. That amount undoubtedly is too small to explain the considerable increase in growth that observers have attributed to dew.

Instead of measuring dew deposition with gages, we can also calculate how much dew could be produced theoretically. Dew is produced when leaf and other surfaces are cooled to a temperature below the dewpoint of the air. This cooling is accomplished by radiation of heat toward the sky.

A large amount of heat is radiated by the sun during the day. The radiation amounts to approximately 1.2 calories per square centimeter a minute. It is transformed partly into long wavelengths and partly into heat of evaporation.

Some of the radiation heats the soil.

Because, on the average, the earth does not become warmer, all radiation absorbed by the ground has to be reradiated by the ground at night in the form of long-wave heat radiation. That radiation is partly absorbed by water vapor in the atmosphere. The drier the atmosphere, therefore, the greater the amount of outgoing heat radiation and the stronger the cooling of the surface will be. On clear nights this radiation amounts to 0.16 calorie per square centimeter a minute at a relative humidity of 100 percent; 0.20 at 40 percent; and 0.25 at 15 percent. As leaves and other surfaces lose heat through the radiation, they are cooled and ultimately may reach the dewpoint of the air. As soon as that happens, dew is deposited and no further drop occurs in the temperature of the leaves.

From the amount of heat exchange we can calculate the amount of dew that can be deposited. At a relative humidity of 40 percent, it takes about 500 calories to lower a sufficient air volume to the dewpoint to deposit a gram of water, which also required about 570 calories of heat of condensation. About half of the radiation, or 0.1 calorie per square centimeter a minute, is therefore available during clear nights for dew deposition. For a whole night that amounts to 1 millimeter of dew. For a whole year of 365 cloudless nights it is equivalent to 15 inches of rain. That amount is rather independent of the relative humidity of the air, because in dry regions the radiation is greater but the amount of dew deposited per calorie is less, whereas in most climates the radiation is less, but it is more effective in producing dew.

These 15 inches of potential condensation from the air is in sharp contrast to the 1.5 inches measured with dew gages. We should try to find the actual amounts of dew that are deposited on a natural cover of vegetation. That has been done in several ways. In the first place, we have a set of measurements by C. W. Thornthwaite and Benjamin Holzman, who measured the water vapor gradient from soil toward the air. By taking into account the rate of air movement, they could calculate how much water vapor was lost or condensed on the basis of this water vapor gradient, and they calculated that a total of 1.81 inches was condensed on a meadow surface for a 10-month period in 1939 in Arlington, Va. During that time, a total of 26.3 inches was received in the form of rain and snow, which would indicate that not more than 7 percent of the total water supply to this meadow had come in the form of dew.

By actual weighings of an area of soil covered with grass, corn, wheat, or other crop plants, the amount of nightly condensation can be measured. That was done in lysimeter experiments at Coshocton, Ohio, by L. L. Harrold and F. R. Dreibelbis. Hourly weighings would indicate the increase or decrease in weight of the blocks of soil. Their increase in weight was due to rain or to dew, but they lost weight through transpiration and evaporation.

In a series of measurements over a 6-year period, it was found that an average equivalent of 9.1 inches of rain was deposited throughout the year in the form of dew—approximately 20 percent of the total water supply came in the form of dew. When we compare this figure with the 15 inches that could theoretically be deposited during 1 year of clear nights, we find that the actual observations agree quite closely with the measured condensation in the lysimeters. We have to take into consideration that on many cloudy nights dew cannot be formed.

Calculations and actual observations apparently agree that dew is a potentially important source of water for plants. As it may amount to about 10 inches of precipitation a year—in line with field experiments such as those of Duvdevani—more work should be carried out to establish the exact conditions under which the greatest amount of dew can be deposited.

As I mentioned earlier, dew can be deposited only when the sky is clear. There is no dew on cloudy nights; semiarid regions therefore are more favorable for dew deposition than most other climates. Not only do clouds prevent the nightly radiation toward the sky; dust and haze also will prevent it. Dusty areas, such as the Sahara, and regions with much haze, like the Los Angeles area, therefore, have very much less dew than areas with clear night skies, such as the southwestern desert areas and Israel.

Considerable differences in the formation of dew can be expected according to the nature of the terrain and velocity of air movement past the condensing surfaces. In completely still air, only the amount of water vapor that can diffuse toward the leaves will be condensed, and that amounts to less than 1 percent of the greatest possible dew deposition. When, on the other hand, strong winds move the air too fast past the leaves, their temperature will not reach the dewpoint, and therefore no dew will be deposited at all. Optimal dew formation can be expected when an intermediate amount of air comes in contact with the leaves.

In the future we should investigate all conditions that affect dew deposition so that it might be possible to increase the effectiveness of dew and increase the amount condensed. It is quite possible, for instance, that by the judicious spacing of trees and shrubs through natural air drainage the optimal amount of air movement can be achieved so that the greatest possible amount of dew will be formed.

Dew seems to be particularly effective in a number of coastal areas around the world. In several such places that have too little rainfall, very heavy dew apparently can carry the crops to maturity without the help of irrigation.

An example is the coast of southern California. Immediately adjoining the ocean is a zone one-half to a few miles wide where tomatoes, peppers, beans, and other vegetables can be grown in summer. Those crops develop well even without irrigation, although no rain falls during the growing season from May to October. The soil in the region may contain enough moisture for the first few months of growth but definitely not enough for the last few months. If growth and production are good nevertheless, that means there must be some other source of moisture. The source can hardly be anything else but dew or coastal fog.

Fogs and mists are really low-hanging clouds in which the water droplets are so small that they do not settle on horizontal surfaces and thus do not register in a rain gage. Consequently they usually are not considered important as sources of water. Yet fogs may be important to plants.

Vegetation in many places where fogs are frequent differs from the vegetation in nearby localities where fogs do not occur. One of the best examples of this is the northern coast of California. Redwoods occur there predominantly in a narrow belt and never range inland beyond the influence of sea fogs. In places where more water is available, redwoods grow very well outside the fog belt—an indication that fog is important in their water economy. In this belt, fogs occur almost daily. Anyone who walks in a redwood forest during a fog finds that the trees are dripping, although in nonforested spots nearby not a drop falls. That means that the redwoods are able to condense the fog droplets to larger drops.

This same dripping of trees in fog one can observe in pine forests in the mountains or under live oaks in the California foothills during autumn fogs. In the latter instance it can be seen that this fog-drip water is effective for the vegetation. Rain would wet equally the ground under and around the trees and therefore would not account for the greener color of the grass or the extensive germination of wild plants under the trees. But during fogs, water drips under the trees and actually moistens the soil within the perimeter of their crowns. If it were merely shade that enables the seedlings to become started or encourages the growth of grass, the green area would extend north beyond the tree. That it does not do.

LET US QUESTION for a moment how trees can condense moisture from fogs. A fog consists of very small (0.01–0.1 millimeter) water droplets, which are far enough apart that they do not fuse, are suspended in saturated air so that they do not evaporate, and are light enough not to settle. Furthermore in a fog there is usually enough air movement to stir up droplets about to settle. When such a fog moves past solid surfaces, it is deflected, and the water droplets flow with the air around the surface and prevent contact with it. If the surface is small or narrow enough, the air is hardly deflected, and the inertia of the water droplets is sufficient to carry them against the surface, where they fuse with it. That means that small or narrow surfaces will act as strainers for the fog droplets. It is an interesting fact that the diameter of pine or redwood needles is such that they condense fog droplets very efficiently at the normal rate of fog movement. That can best be seen in hoarfrost or rime, which develops when a fog touches surfaces, where the condensed fog droplets freeze immediately upon contact if the temperature is below freezing. Under such conditions a ribbon of ice extends from telephone and other wires in the direction from which the wind came. But we also see that hoarfrost covers all pine needles, although the larger leaves of broadleaved trees have hoarfrost only along their edges and not over their surfaces. That shows how much more effective the needle form is for condensing fog droplets.

We can now return to the effectiveness of fog as a source of water in nature. Stagnant mists cannot serve as a source of water because the condensation occurs only when a sufficient volume of air with fog droplets is carried over the condensing surface.

Therefore the ground mist developed through rapid cooling at night of the air nearest the soil is ineffective for condensation of the fog particles. But coastal fogs formed by moisture-laden air rising against coastal ranges, or clouds forming against the mountain ranges by lateral air movement which forces air up against the mountain slopes, are ideal for fog condensation.

In regions where such fogs occur rather regularly, a tree or shrub vegetation grows that is rich beyond what the actual precipitation records would make one expect. Along the California coast, the redwood growth is phenomenal against the western slopes, but against the eastern slopes, with approximately equal amounts of rain, tree growth is much poorer. The difference indicates the degree to which water precipitation from fogs is effective.

In the drier areas in the West, there are series of high mountain ranges in areas with insufficient precipitation for tree growth. On the mountains we find a lower timberline, below which trees do not grow. If the timberline were due to reaching the threshold value of precipitation where tree growth was barely possible, one would expect a ragged and irregular timberline, with the trees gradually thinning out.

But along the eastern slopes of the Sierra Nevada, for example, one sees a sharp horizontal line of demarcation, below which no trees occur and above which a normal pine forest is found. The line coincides with the level at which clouds are formed by eastern winds.

IN MANY DRY REGIONS, such as the areas covered with chaparral in California, many of the most characteristic plants, such as chamise (*Adenostoma fasciculatum*) or wild buckwheat (*Eriogonum fasciculatum*) have developed very small leaf surfaces in the form of needlelike leaves. They are not an adaptation to reduce transpiration, as is often suggested, but probably are effective in condensing water from the occasional fogs.

In dry regions bordering a coast, we may find so-called fog deserts, areas with very little precipitation but with frequent fogs. Typical of such areas are southwestern Africa and the coast of Peru. In both, mountains rise immediately behind the coast and cause the formation of fog as the air rises against them. In each, also, a cold ocean current (the Benguela and the Humboldt Currents) limits the total amount of moisture present in the air, so that the total precipitation is about 1 inch a year. The lowlands near the coast, where no fog occurs, are practically without vegetation, but at 1,000 feet a shrub vegetation beyond expectation occurs where fogs hang most of the year. Indicating the high humidity during most of the day is the richness of the epiphyte vegetation. Even on cacti, like *Trichocereus*, grow many lichens and several tillandsias, which ordinarily are found in moist rain forests. And on the trees (*Caesalpinia* and *Zizyphus*) mosses and peperomias cover the branches, which consequently seem several times thicker than they are.

The importance of the actual condensation of fog droplets in fog areas can be seem in several places. Just north of San Diego there is a small area where the Torrey pine occurs. The trees are limited to the upper parts of the slopes facing the ocean—that is, where the fog comes in closest contact with the vegetation. On the lower parts of the slopes and a few hundred feet inland, the pines disappear. It is an otherwise very dry area, as indicated by the much poorer shrub vegetation anywhere except on the ridges bordering the ocean. A similar phenomenon can be observed along the Mediterranean coast. Just behind Oran in Algeria rises a plateau with a rainfall of about 15 inches—enough for some pines but not enough for the holly oak (*Quercus ilex*). However, this oak is found only along a strip 10 feet wide that follows the ridge of the tableland, again the place where fog will hit most and where (through droplet condensation) the water supply is more abundant.

One can get an idea of the total amount of liquid that can be precipitated by such fogs by using a rain gage, over which a set of fine wires or branches is placed. The wires or the branches will condense the fog droplets, which then drip into the rain gage. Such an arrangement disclosed that during a particularly heavy storm, when clouds were swept over the Table Mountain in South Africa, only 0.2 inch of precipitation fell in a regular rain meter, but in a similar rain gage, in which branches had been placed, 6 inches of precipitation was collected. It seems a worthwhile project to investigate this fog condensation in greater detail.

THE RELATIVE HUMIDITY of the air may be important in the conservation of water by plants. Under otherwise identical conditions, water loss by transpiration will be proportional to the saturation deficit of the air. As the saturation deficit increases beyond a certain point, however, phenomena (such as incipient drying) stop a further increase in transpiration. Plants that themselves have a saturation deficit will lose water toward the atmosphere only if the saturation deficit of the air is greater than that of the plants. At a diffusion pressure deficit, or suction force, of 100 atmospheres, such as can be found in arid regions, plants will be in equilibrium with air having a relative humidity of 93 percent. That is to say that they will lose water by transpiration only when the air is drier than 93-percent relative humidity but will take up water vapor from the air when this is more moist than 93 percent. In a number of experiments, E. C. Stone, C. L. Young, and I found that several chaparral plants can take up water vapor from air with a relative humidity of 85 percent or more.

Therefore we should consider the possibility that absorption of water vapor can be a source of water for certain plants. This I found to be true of several tropical orchids, which hang from the branches of jungle trees and obtain liquid water only during actual rainstorms. When the relative humidity in the forest was 95 percent or more, the orchids took up water vapor and increased in weight. Since the relative humidity inside such forests remains above 95 percent more than 12 hours a day, water vapor was a significant source of water for the plants.

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Conversion of Saline Waters

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Reclaiming water from otherwise unusable sources, by removing dissolved salts from saline water, is coming to be regarded as a probable way to supplement our traditional water supplies.

The process is known as conversion or the demineralization of saline or sea water. One of the sources is the relatively static and indispensable water of the oceans, which contain most of the world's water. Its use would supplement the short supplies along coastal areas. Another source is the brackish water now found inland—much of which is becoming increasingly saline to a point where it can no longer be used for some purposes without harmful effects.

In either case, the salts held tenaciously in solution must be removed before the water becomes suitable for agriculture, industry, or domestic use.

Although sand, sediment, and other foreign particles can be removed simply by filtration, salt cannot be removed so easily.

Saline water is a relatively simple system of inorganic salts dissolved in water. It has certain physical and chemical properties that determine the various methods by which the salts may be separated from the water. The system, although not complex, is comparatively stable; because of the stability, separation of saline solutions requires relatively large quantities of energy.

Theoretical calculations show that at least 2.8 kilowatt-hours (3.8 horsepower-hours) of electrical energy is required to separate 1,000 gallons of pure water from sea water. Thus, more than 900 kilowatt-hours (more than 1,200 horsepower-hours) must be used to obtain 1 acre-foot of fresh water from sea